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P1_2 Gravity in Space

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Abstract

With the dream of travelling among the stars and visiting other planets comes a lot of problems. Aside from the obvious problems of the current limit on technology in space travel there are long-term biological effects of zero-g travel on humans. Thus this paper details the feasibility of utilising gravitational effects via rotation to provide an artificial gravity environment during space flight. It is found that to produce a comfortable environment of $1g$ in a spacecraft would require rotation around an axis of distance ~99 m from the centre of the spacecraft which is believed to be an unfeasible solution for current spacecraft for multiple reasons.

Introduction

For a long time it has been the dream of man to travel amongst the stars visiting other planets and moons; however, beyond the moon landings this has been nothing but a pipe dream not only due to our technological advancement within space travel but also the harsh effects of space on the human body. One such harshness of space travel upon the body is that of the effect of gravity, or more correctly so, the lack thereof in a microgravity environment.

The absence of gravity during time in space can have multiple effects including space adaptation syndrome (SAS) [1], also known as space motion sickness, which occurs due to the vestibular system adapting to weightlessness; but more seriously, is the decrease in bone density over long periods of time in space. Whereas the effect of SAS usually passes within the first few days of space travel, the decrease in bone density with time is incredibly serious as it can leave permanent effects on the astronauts. One such solution to avoid the decrease in bone density is to simulate the effect of gravity on the spacecraft via rotation about an axis; this is known as artificial gravity.

Theory

By rotating a spacecraft about an axis, the effect of gravity will be present within the inside wall of the hull of the craft. This rotation gives the effect of gravity by driving objects inside the spacecraft to the inside hull surface. This 'force' is sometimes referred to as the fictitious force know as the 'centrifugal force' but the gravitational effect is more correctly attributed to the objects within the hull feeling inertia and attempting to travel in a straight line. Since the objects in the spacecraft cannot continue to travel in a straight line (without leaving the spacecraft interior), the combination of the spacecraft rotation and the hull provides a centripetal force allowing the objects to travel in a circle. This leads to further confirmation of Newton's Third Law with the artificial gravity felt by the objects being just the normal reaction force of the objects with the hull reacting with this centripetal force.

Although this artificial gravity allows for a remarkable effect of gravity to an observer rotating along with the habitat, it is fundamentally different in several ways. First is that, whereas 'real' gravity pulls towards the centre of a massive body, the 'centrifugal force' pushes away from the axis of rotation; this leads to the magnitude of the artificial gravity varying proportionately with distance from the centre of this axis of rotation. This initially sounding minor point actually has the great implications of the gravity felt at an astronauts head being significantly different to that felt at their feet, thus hindering movement. Another phenomenon of artificial gravity is that of the Coriolis Effect. This effect gives the apparent observation of a force tending to curve the motion of an object in the opposite direction to that of the rotating habitat. Such effects have major implications on the inner ear of a human inducing dizziness, nausea and disorientation (similar to the effects of SAS within the first few days of weightlessness). Experiments have been done to show that a combination of slower rotations about the axis and/or larger rotational radii can help to eliminate both of these effects.

Quantitative Analysis

It has been deduced [2] that rotational rates of less than $3\ rpm$ should result in little to no adverse Coriolis effects and that rates of several rpm should be avoided. By considering Newton's second law and centripetal forces felt during the rotation, Eq. 1 is found. The radius of rotation required to experience an artificial gravity of $1g$ (as is at the surface of the Earth) can be determined via simple manipulation to Eq. 1.1.

$$g' = \frac{R\left(\frac{\pi}{30}*rpm\right)^2}{9.81}, \qquad (1)$$

$$R = 9.81g'\left(\frac{30}{\pi*rpm}\right)^2, \qquad (1.1)$$

where g' is the fractional value of gravity compared to that on Earth, rpm is the revolutions per minute and R is the radius from the centre of the axis of rotation. Using a value of $g' = 1$ and $rpm = 2$, it is found that the radius about the central rotational axis is $R \sim 99\ m$.

Conclusions

The quantitative analysis of this problem heralds a radius of $\sim 99\ m$ from the centre of rotation to be able to produce a comfortable (Coriolis effects taken into account) level of artificial gravity upon the spacecraft which should also be at a large enough distance to negate centrifugal gravity effects. This distance however poses the problem of being quite large, leading to sweeping out a circumference of $\sim 622\ m$ twice every minute. This leads us back to the initial problem of our technology not being advanced enough to achieve this realistically. Previous work [3] has found that the space shuttle is capable of a pitching manoeuvre, at a rate of $7rpm$ that could produce an artificial gravity environment that astronauts may be able to adapt to. However with the recent retirement of the shuttle, there is no current technology that may provide a viable solution. Although this solution of making long-term space travel more bearable on astronauts (and thus limiting the permanent effects on bone density) seems unfeasible, it is not fully understood what the minimum gravity required for no adverse effects on bone density is, which may lead to a much smaller value of g' required for production of artificial gravity through rotational methods thus higher feasibility of this option. However, before this can even be considered, major technological advancements in space travel are required of which we now look towards the private sector for solutions.

References

[1]http://www.esa.int/esaHS/ESAGO90VMOC_astronauts_0.html. ESA, 2004. [Accessed 7/10/11].

[2]http://www.nss.org/settlement/nasa/75SummerStudy/Chapt3.html. *Space Settlements: A Design Study,* Stanford University. Chapter 3. [Accessed 7/10/11]

[3]A. Bukley, G. Clement and D. Lawrence, Acta Astronautica, 60, 472 - 478, 2007.